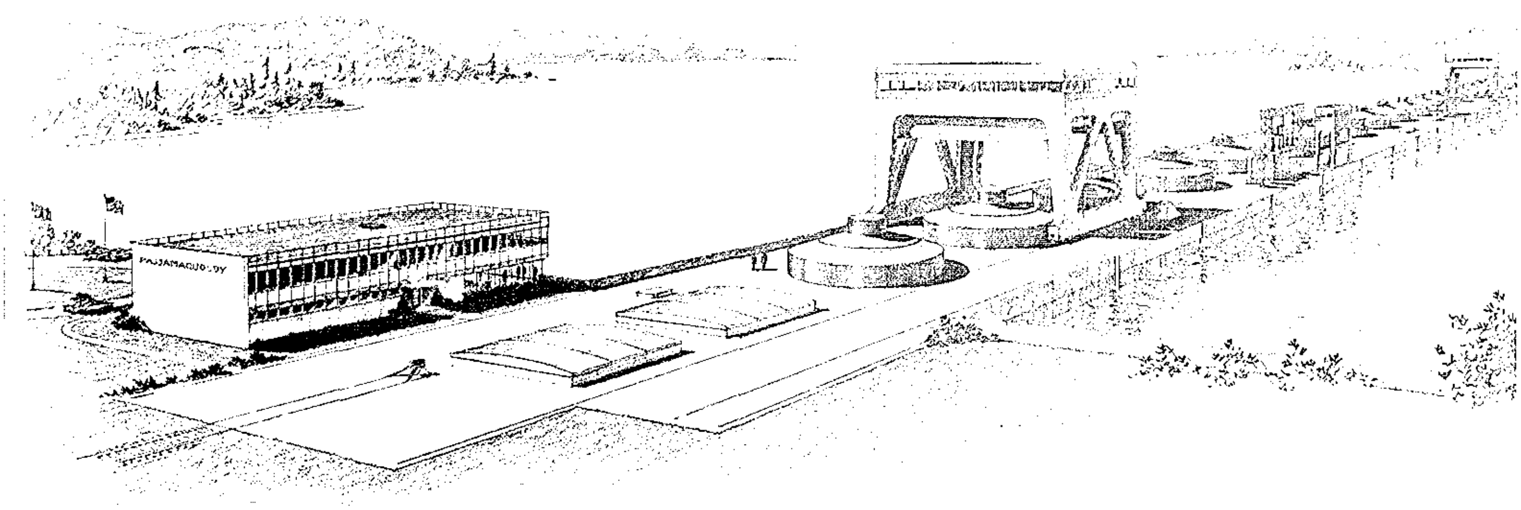
INVESTIGATION OF THE INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT



BROCHURE

REPORT TO THE INTERNATIONAL JOINT COMMISSION BY THE INTERNATIONAL PASSAMAQUODDY ENGINEERING BOARD

October 1959

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Low tide—Eastport, Maine

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In accordance with United States Public Law 401, 84th Congress, 2nd Session, and the Boundary Waters Treaty of 1909, the Governments of Canada and the United States in August 1956 directed the International Joint Commission to investigate the engineering and economic feasibility of harnessing the tides of Passamaquoddy and Cobscook Bays in the Province of New Brunswick and the State of Maine for production of hydroelectric power. The investigation, completed in October 1959 well within the appropriations authorized by both countries, established the type and cost of the most economical project to generate electricity from the tides, and determined whether tidal power could be generated at a price competitive with the most economical alternative source of power.

To carry out the investigation of the tidal power project and its effect on the economies of the United States and Canada, including the fisheries of the area, the Commission established two separate boards, the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board. Composed of two representatives each from Canada and the United States, the boards were directed to coordinate their studies and to submit separate reports to the Commission. The Engineering Board in turn established an Engineering Committee to supervise the detailed investigations. These investigations were carried out primarily by the U.S. Army Engineer Division, New England, Corps of Engineers, and the Regional Office of the United States Federal Power Commission, New York. Canadian aspects of the survey were conducted by the Department of Public Works, the Department of Northern Affairs and National Resources, and other agencies of the Federal and Provincial Governments of Canada . This syllabus presents a brief summary of the report of the International Passamaquoddy Engineering Board, including the Board's conclusions on engineering and economic feasibility.

HARNESSING THE TIDES

Man has for centuries devised methods of putting the ocean tides to work. As early as the eleventh century tides were harnessed in a small way in England and other Western European countries when small tide mills were used to grind corn. In Chelsea, Massachusetts, in 1734 "Slade's Mill" was built to grind spices. This mill developed about 50 horsepower from four water wheels driven by the head created by damming a small estuary to trap water at high tide. Since the advent of hydroelectric power, numerous tidal power sites throughout the world have been investigated. In addition to the Passamaquoddy Bay area, a few of the locations recently studied for large tidal power plants include the tidal estuary of the River Severn in England, the Bay of L'Aber Vrach on the northwest coast of Brittany, Mont St. Michel in northwest France near St. Malo, and the Gulf of San José in Argentina. Components of what may be the world's first large-scale tidal power plant are now being tested to harness the La Rance River estuary on the Brittany coast.

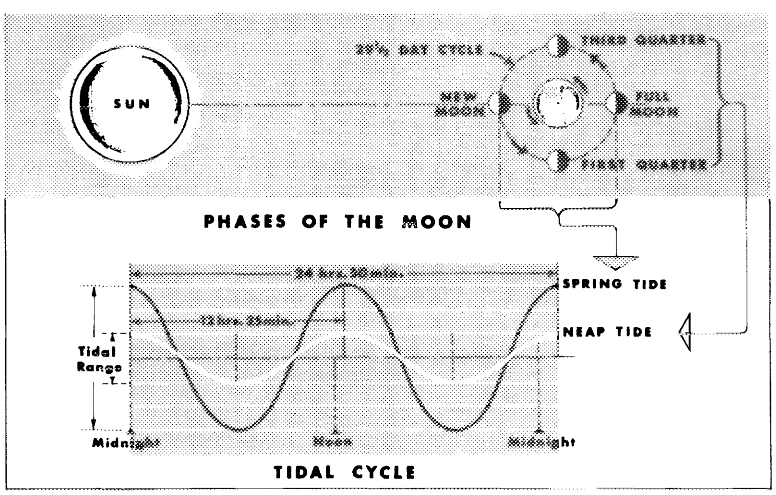
Tidal hydroelectric power, similar to river hydro power, can be produced by a flow of water from a higher to a lower level through hydraulic turbines. A single pool equipped with gates may be built to trap water at high tide and discharge through turbines to the ocean at low tide, or the pool may be emptied at low tide to receive turbine discharge from the ocean at high tide. Two separate pools equipped with emptying and filling gates may be used, one pool filled at high tide and the other emptied at low tide, with the high pool discharging through the turbines into the low pool.

A single high pool has the serious disadvantage of producing discontinuous power, because no power can be generated without a sufficient difference between the level of the pool and the level of the ocean. Thus no generation is possible until the ocean has receded sufficiently to obtain this difference in water levels, or power head; nor is generation possible on the rising tide after the level of the ocean becomes too high to provide this minimum necessary head. For similar reasons, a single low pool also produces interrupted power. This disadvantage is avoided in the two-pool plan, the plan adopted for the project described in this report, which generates varying but continuous amounts of power. This continuous power is achieved in the two-pool plan by operating emptying and filling gates so that the level of one pool is always sufficiently higher than the other.

The advantages of a tidal power plant are that the tides, which can be predicted with accuracy for many years in the future, can produce power unaffected by droughts, floods, ice jams, or silting -- adverse factors which decrease the output and limit the life of river hydroelectric plants. An inherent disadvantage of the tides as a source of power is that the tides, following the gravitational pull of the moon as it passes overhead every 24 hours and 50 minutes, are out of phase with the 24-hour solar day. This 50 minute daily lag is fundamental to the economics of tidal power for, since power output varies with the tides, tidal power is completely out of step with the normal patterns of daily use of electricity. Therefore, unless the tidal plant is supplemented by an auxiliary power plant, such varying power would be of little value.

Tidal ranges, the height between high and low tides, determines the available head and thus governs the amount of power generated. Tides are caused by the changing relationship of the sun, earth and moon with respect to each other, and tidal range, which is affected primarily by the phases of the moon, also varies from day to day. As shown in the simplified illustration, the sun and moon appear on the same side of the earth approximately every four weeks, at the time of new moon. Two weeks later, at the time of full moon, the sun and moon appear on opposite sides of the earth. When either of these conditions occurs, gravitational attraction of the sun and moon reinforce each other and cause maximum or spring tides. When the moon is at either quarter phase, the gravitational attraction of the sun and moon are approximately at right angles with respect to the earth, causing minimum or neap tides. When the moon is new or full and simultaneously in perigee -- the point in the moon's orbit closest to earth -- the spring tide is particularly great.

The height the tide will reach is also affected, sometimes to a high degree, by the coastline. On open, exposed headlands tides may range from 4 to 5 feet, while in nearly landlocked embayments, like the Mediterranean, tides are negligible. In the Gulf of Maine, however, which opens toward the deep areas of the Atlantic Ocean as the continental shelf drops off beyond Georges and Browns banks, the tides are greatly amplified by the size and configuration of the shore and bottom. As shown on plate 1, the mean tidal ranges become progressively greater as the tides move into the Gulf of Maine toward the mouth of the Bay of Fundy. The funnel-shaped Bay of Fundy again amplifies the tidal range, producing the highest tides in the world at the head of the bay. To devise a workable and feasible scheme to harness these tides for the economical production of uninterrupted power constitutes the essence of tidal power engineering.



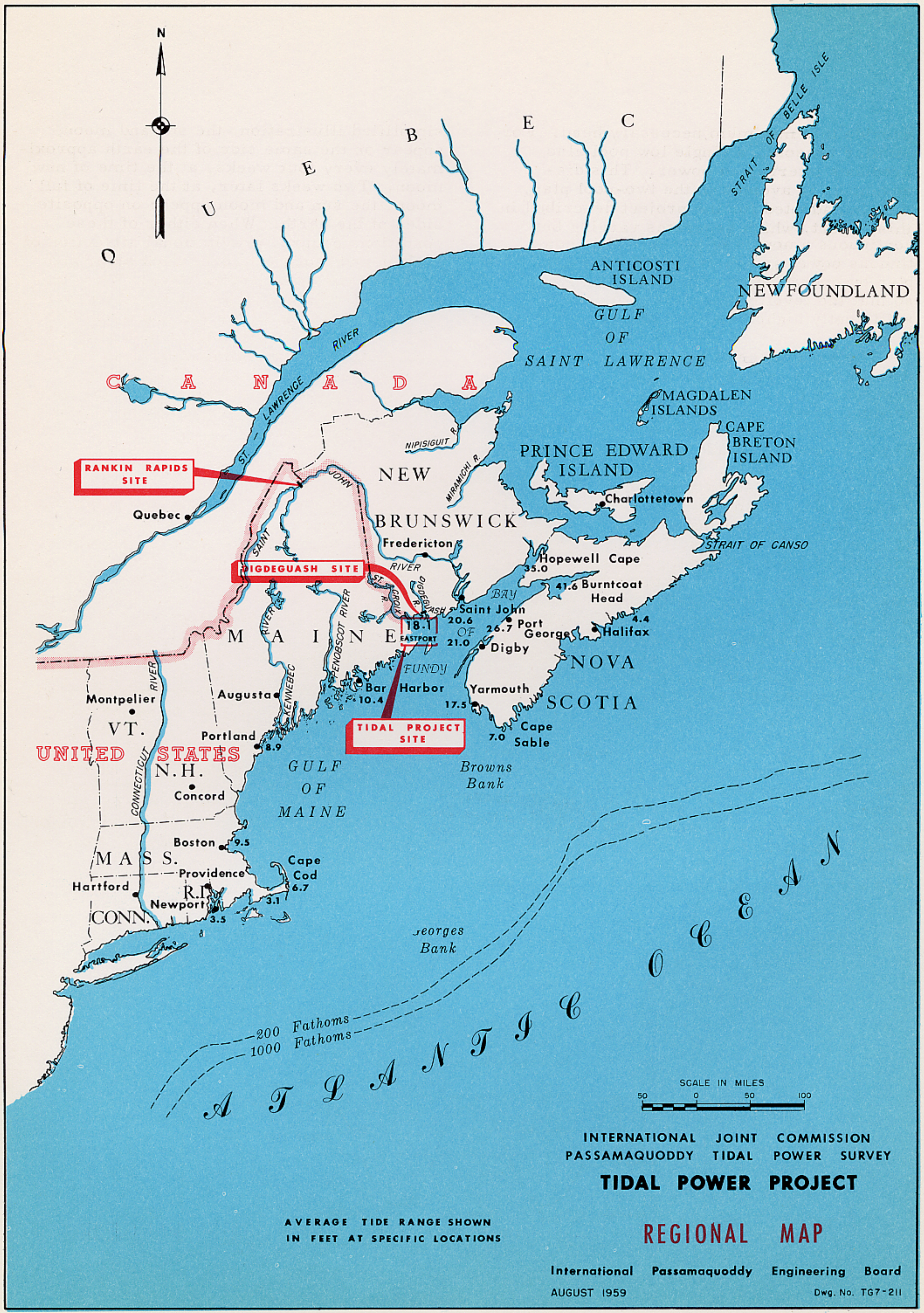

QUEBEC
CANADA
ST. LAWRENCE RIVER
ANTICOSTI ISLAND
GULF OF SAINT LAWRENCE
NEWFOUNDLAND
STRAIT OF BELLE ISLE
MAGDALEN ISLANDS
CAPE BRETON ISLAND
PRINCE EDWARD ISLAND
Charlottetown
STRAIT OF CANSO
NIPISIGUIT R.
MIRAMICHI R.
NEW BRUNSWICK
RANKIN RAPIDS SITE
Quebec
SAINT JOHN RIVER
Fredericton
DIGDEGUASH SITE
ST. CROIX R.
DIGDEGUASH R.
Hopewell Cape
35.0
41.6 Burntcoat Head
Saint John
20.6
BAY OF FUNDY
26.7
21.0
Port George
Digby
4.4 Halifax
18.1
EASTPORT
NOVA SCOTIA
MAINE
KENNEBEC RIVER
PENOBSCOT RIVER
Augusta
Bar Harbor
10.4
Yarmouth
17.5
Cape Sable
7.0
TIDAL PROJECT SITE
Montpelier
VT.
UNITED STATES
CONNECTICUT RIVER
Portland
8.9
N.H.
Concord
GULF OF MAINE
Browns Bank
Boston
9.5
MASS.
Cape Cod
6.7
Providence
Hartford
R.I.
Newport
3.1
3.5
CONN.
Georges Bank
ATLANTIC OCEAN
200 Fathoms
1000 Fathoms
SCALE IN MILES
50 0 50 100
AVERAGE TIDE RANGE SHOWN IN FEET AT SPECIFIC LOCATIONS
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
REGIONAL MAP
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-211

PLATE 1

Generation of hydroelectric power from the tides within the Bay of Fundy has intrigued engineers in Canada and the United States for over forty years. At Burntcoat Head in the Minas Basin at the head of the Bay of Fundy in Canada, the spring tides reach an extreme range of over 50 feet. The range of the tides in Passamaquoddy and Cobscook Bays near the mouth of the Bay of Fundy, the site of the tidal project described in this report, varies from a minimum of 11.3 feet at neap tide to a maximum of 25.7 feet at spring tide, averaging 18.1 feet. During each tidal cycle, an average volume of approximately 70 billion cubic feet of water regularly enters and leaves Passamaquoddy and Cobscook Bays.

As early as 1919, W. R. Turnbull of Saint John, New Brunswick, suggested production of hydroelectric power from the great tides at the head of the Bay of Fundy in the Petitcodiac and Memramcook estuaries. In 1945 this site was again investigated by Canadian engineers but the proposed tidal project proved uneconomical.

Dexter P. Cooper made the first large-scale study of potential power production in Passamaquoddy and Cobscook Bays in the early 1920's. The most extensive of the many plans Cooper studied was an international project using both Passamaquoddy and Cobscook Bays. Each bay was to be closed by a series of dams, together with regulating gates and navigation locks, to form a two-pool tidal project. Power was to be generated by discharging water from the high pool in Passamaquoddy Bay to the low pool in Cobscook Bay through turbines in a powerhouse located between the two pools. Cooper also planned an auxiliary pumped-storage plant to supplement the fluctuating tidal power. Cooper, however, lost support during the financial crisis of 1929 and his plans were never realized.

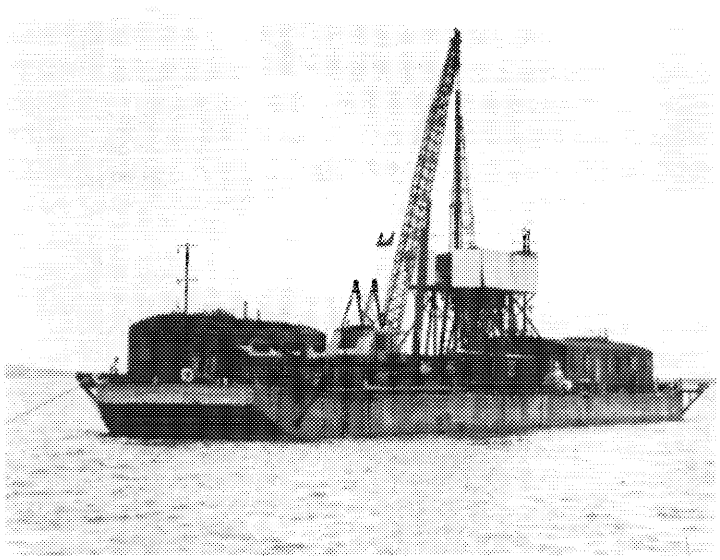
In 1935 the Government of the United States undertook development of a single-pool project using only the waters of Cobscook Bay on the United States side of the international boundary. Although this work was suspended in 1937 when no further funds were made available, the surveys, investigations, and construction of three small dams completed by the Corps of Engineers proved of great value to the present investigation.

The major differences between the 1935-37 project and the project which is the subject of this report are that (1) the project proposed in this report is an international two-pool project which permits production of continuous power; and (2) that a river hydroelectric auxiliary plant is used to firm the tidal plant output. Compared to the single-pool project planned in 1935-37, these differences are highly advantageous.

As the result of continued interest in the Passamaquoddy tidal power project on the part of the people of Maine and New Brunswick, supported by an increasing awareness of the need to exploit all possible sources of energy, the International Joint Commission was requested in 1948 by both governments to review all previous reports and to estimate the cost of carrying out a complete study in order to decide conclusively the engineering and economic feasibility of a large-scale international tidal power project in Passamaquoddy and Cobscook Bays. This report, completed in 1950, led directly to the present 1956-59 survey. The present study is the first investigation sufficiently comprehensive to permit the Governments of Canada and the United States to determine the economic justification and advisability of developing an international tidal power project in Passamaquoddy and Cobscook Bays.

FIELD INVESTIGATIONS

In order to determine the best layout of an international tidal power project, it was first necessary to conduct a series of field investigations and studies of site conditions in the Passamaquoddy-Cobscook area. Full use was made of all data gathered in previous studies, particularly those made by the U.S. Army Corps of Engineers in 1935-37. A field office and soils laboratory were established in Eastport, Maine, to gather and analyze new basic data. Aerial topographic surveys, tidal observations, hydrographic surveys, and subsurface explorations by deep-water core drilling and sonic methods were made in areas not investigated during any of the several earlier studies of the project area. Underwater mapping and exploration using recently developed sonic equipment furnished bottom contours and valuable foundation data.



Deep-water core drilling in Friar Roads

Core drilling in great water depths and high tidal velocities to determine the design and location of deep rock-filled dams and emptying and filling gates was the largest and most costly phase of the field investigations. To accomplish the difficult task of core drilling in waters up to 300 feet deep swept by reversing tidal currents reaching velocities of 6 to 10 feet per second, a 240-foot barge equipped with a special drilling assembly was brought from the Gulf of Mexico specifically for this task. With this equipment, samples of undisturbed overburden and bedrock were successfully taken for analysis from 15 carefully selected borings. Properties of these samples were analyzed in the laboratory of the Eastport field office. As the field investigations progressed, all new information was used to determine the best project arrangement -- the location of dams, gates, locks, powerhouse, and other components of the tidal project.

THE PROJECT SELECTED FOR DESIGN

From comparative analyses of a number of single-pool and double-pool schemes, it became evident that conditions at Passamaquoddy are particularly well suited to a two-pool tidal power project.

The topography of the Passamaquoddy-Cobscook areas permits many different arrangements of the components of a large-scale, two-pool project. Before the best arrangement could be selected, preliminary estimates were made to determine the power output and cost of numerous different project arrangements. Five of the most promising arrangements were then studied in greater detail. To avoid time-consuming and costly computations of energy output, this work was done by an electronic computer. In this way annual energy generation could be determined rapidly for any project arrangement once its pool areas and the optimum number of its generating units were established. The project arrangement that revealed the best relationship of installed capacity and energy output to construction cost was then selected for design.

The project arrangement thus selected for specific design and cost estimates includes the 101 square miles of Passamaquoddy Bay as the high pool and the 41 square miles of Cobscook Bay as the low pool, with a 30-unit powerhouse located at Carryingplace Cove, as shown on plate 2. With 30 generating units rated at 10,000 kilowatts each, operated at 15 percent above rated capacity for short periods during spring tides, the output of the tidal power plant would range from 95,000 to 345,000 kilowatts. Average energy generation would be 1,843 million kilowatt-hours a year.

With the major aspects of the best project layout determined, specific design studies were undertaken of each component of the selected plan -- tidal dams and cofferdams, filling and emptying gates, navigation locks, the powerhouse, turbines and generators -- to a point that would permit reliable cost estimates.

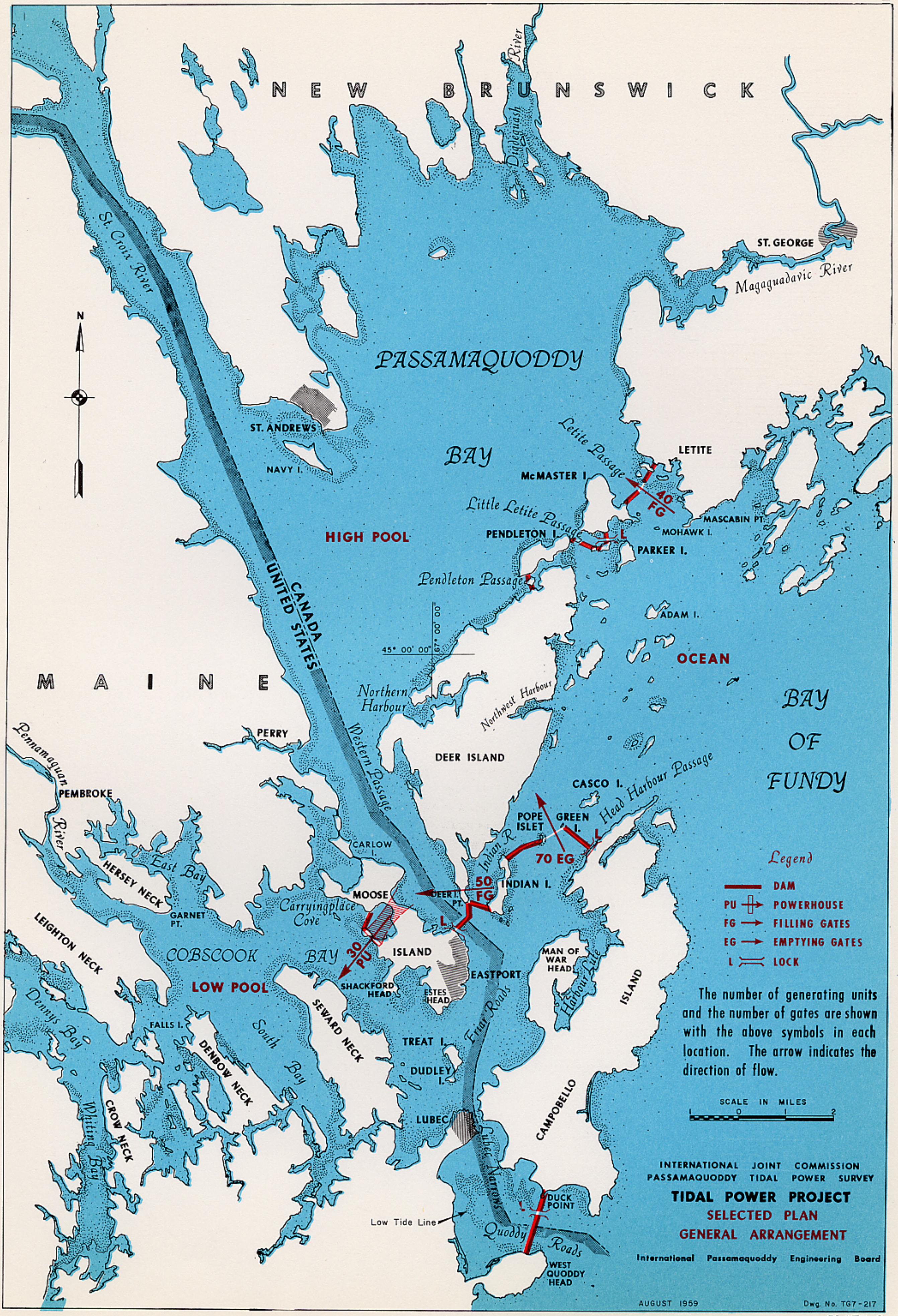

NEW BRUNSWICK
Digdeguash River
St. Croix River
ST. GEORGE
Magaguadavic River
PASSAMAQUODDY
BAY
ST. ANDREWS
NAVY I.
Letite Passage
LETITE
McMASTER I.
40 FG
Little Letite Passage
MASCABIN PT.
MOHAWK I.
PENDLETON I.
L
PARKER I.
HIGH POOL
Pendleton Passage
CANADA
UNITED STATES
ADAM I.
45° 00' 00"
67° 00' 00"
OCEAN
MAINE
Northern Harbour
Northwest Harbour
BAY OF FUNDY
PERRY
Western Passage
DEER ISLAND
Pennamaquan River
PEMBROKE
CASCO I.
Head Harbour Passage
POPE ISLET
GREEN I.
Indian R.
70 EG
L
CARLOW I.
East Bay
HERSEY NECK
MOOSE
DEER PT.
50 FG
INDIAN I.
GARNET PT.
Carryingplace Cove
L
LEIGHTON NECK
COBSCOOK
BAY
30 PU
ISLAND
MAN OF WAR HEAD
LOW POOL
EASTPORT
Harbour Lite
ISLAND
SHACKFORD HEAD
ESTES HEAD
SEWARD NECK
Dennys Bay
FALLS I.
South Bay
Friar Roads
DENBOW NECK
TREAT I.
DUDLEY I.
CAMPOBELLO
CROW NECK
Whiting Bay
LUBEC
Lubec Narrows
DUCK POINT
L
Low Tide Line
Quoddy Roads
WEST QUODDY HEAD
Legend
DAM
PU POWERHOUSE
FG FILLING GATES
EG EMPTYING GATES
L LOCK
The number of generating units and the number of gates are shown with the above symbols in each location. The arrow indicates the direction of flow.
SCALE IN MILES
1 0 1 2
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
SELECTED PLAN
GENERAL ARRANGEMENT
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-217

PLATE 2

DAMS AND COFFERDAMS

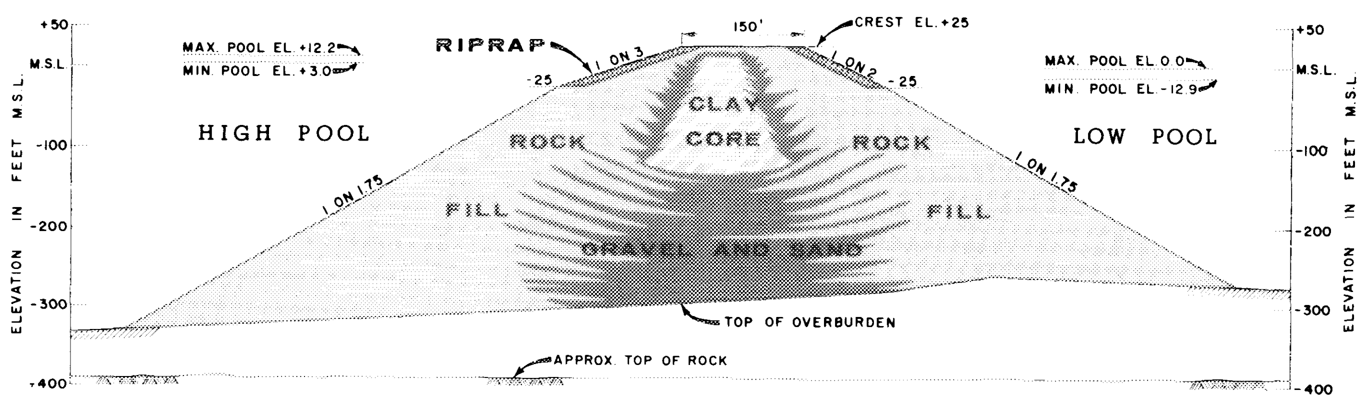
The selected project would require construction of nearly seven miles of rock-filled dams. With tidal velocities as high as 10 feet per second during the 26-foot high tide, the difficulties of constructing sufficiently water-tight tidal dams, small portions of them in depths ranging from 125 to 300 feet, and closing these dams in the face of restricted and greatly increased tidal velocities up to 20 feet per second, posed engineering and design problems without precedent. In view of these problems, several outstanding specialists in the fields of hydraulic engineering and soils mechanics were consulted, and model studies were made of the hydraulic characteristics of deep tidal dams to determine the best and most economical design and methods of construction.

Bottom conditions in Passamaquoddy and Cobscook Bays vary widely from areas of exposed bedrock to clay overburden more than 100 feet thick. The 35,700 linear feet of tidal dams are located as far as practicable on foundations of bedrock or granular material to avoid clay overburden. The tidal dams, composed of a clay core supported by flanking dumped-rock fills, are designed to permit greatest possible use of materials excavated for the gate structures, navigation locks and the powerhouse.

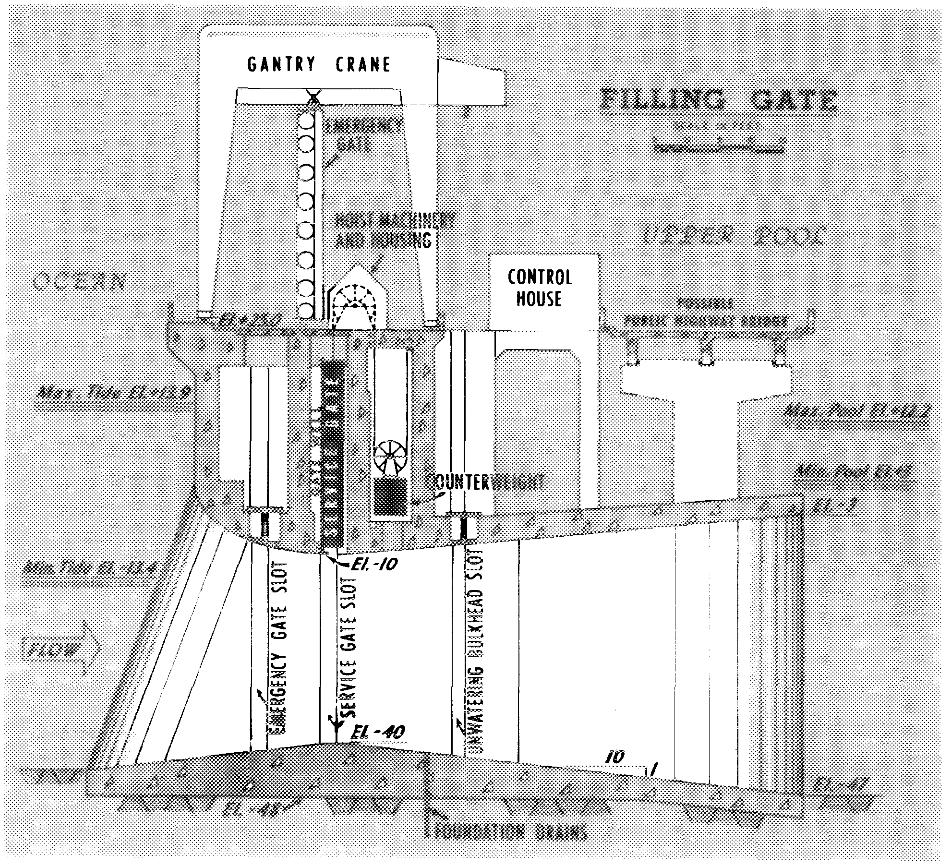
Of some 17 million cubic yards of clay which must be excavated from Carryingplace Cove for the powerhouse, the greater portion would be used in the clay cores of the dams to depths of 125 feet. About 2,900 linear feet of dams, or 8 percent of the total length of tidal dams in the project, would be located in water depths varying from 125 feet to about 300 feet below mean sea level. At these greater depths a granular core would be placed by special bottom-dump buckets. With the exception of these deep, granular core sections, the tidal dams can all be built with conventional land and marine equipment.

Construction of the dams would be scheduled to permit direct placement of material excavated for the powerhouse, gates, and navigation locks without costly stockpiling and rehandling. To overcome the problem of greatly increased tidal currents during closure of the dams, the 160 emptying and filling gates would be constructed first and operated to handle part of the tidal ebb and flood, thus reducing the quantity of water passing through the closure sections.

Cofferdams of several different types, depending upon the depths to be unwatered, would be used to excavate for the foundations of the powerhouse, filling and emptying gates, and navigation locks. Cofferdam designs include embankments, log cribs with timber sheathing, and steel sheet piling of both circular and cloverleaf design. Construction of the emptying gates in Head Harbour Passage would entail an embankment cofferdam 120 feet below mean sea level under a head of 75 feet when pumped out. Construction of cofferdams of this magnitude, built to withstand water pressures far greater than those on the tidal dams themselves, constitutes one of the major engineering and construction tasks of the Passamaquoddy tidal project.



WESTERN PASSAGE DAM



FILLING AND EMPTYING GATES

The project plan includes 90 filling gates, 40 in Letite Passage and 50 between Western Passage and Indian River, as shown on plate 2. In the reach between Pope and Green Islets 70 emptying gates, similar to the filling gates but set at a lower elevation, would empty the lower pool. Comprehensive study of all types of gates, and detailed examination of nine of the most feasible, led to the selection of a 30' x 30' vertical-lift steel gate set in a venturi throat. Early in the study a crest gate with a vertical-lift leaf appeared to promise economy because of high flow capacity, but the costs of auxiliary structures and maintenance to prevent icing more than offset its lower construction cost and superior hydraulic capacity. The venturi throat was selected because, among other important advantages, it permits maximum discharge for a given gate area.

NAVIGATION LOCKS

The project would have four navigation locks. The dimensions and locations of the navigation locks were selected to accommodate present traffic in Passamaquoddy and Cobscook Bays, with an allowance for a modest increase in the size of ships using the area. Two locks, one at Little Letite Passage and one at Quoddy Roads, would have clear dimensions of 95' x 25' x 12' to pass fishing vessels. Two locks, one at Head Harbour Passage immediately east of the emptying gates and one at Western Passage north of Eastport, would have clear dimensions of 415' x 60' x 21' to pass vessels somewhat larger than the present traffic. The reversing head on the locks ruled out the use of miter gates in favor of sector gates, which have proved successful under similar conditions at numerous locks on the Intracoastal Waterway in the Gulf of Mexico and on the Sacramento River.

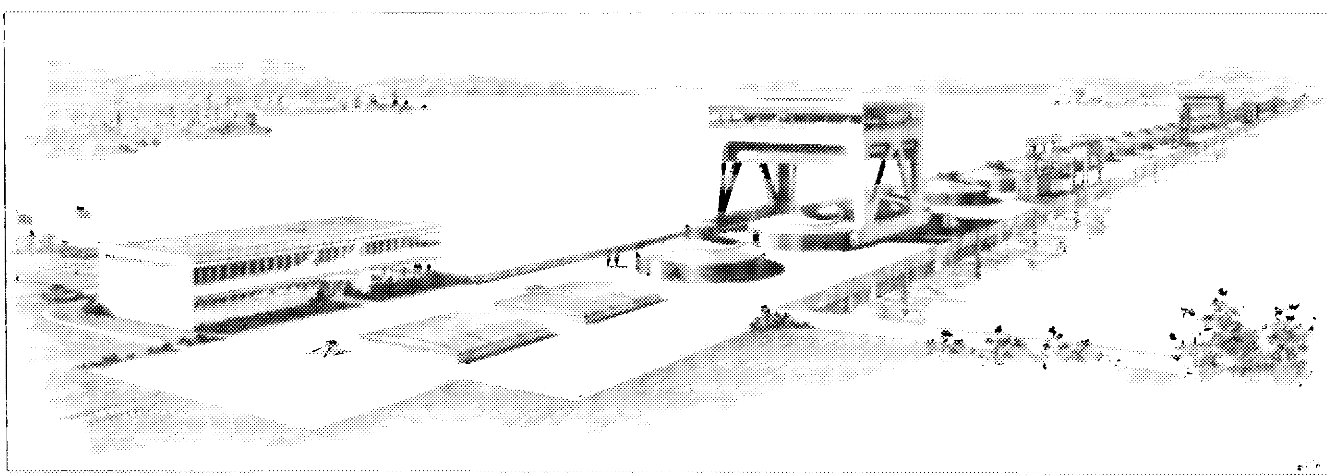
POWERHOUSE

Located northwest of Eastport in Carryingplace Cove, the powerhouse would contain 30 turbine-generator units, each placed in a concrete monolith 78 feet wide and 176 feet long in the direction of flow, with the bottom of the draft tube 110 feet below the powerhouse deck. The outdoor powerhouse shown in the architect's rendering proved more economical than partially or fully-housed types. The generators would be protected by weatherproof housings on the powerhouse deck and serviced by two large travelling gantry cranes equipped with moveable doors to enclose and protect the generators while being serviced. All control equipment would be located on the turbine room floor under the top deck of the power-house. All metal parts of the powerhouse and of all other components of the tidal project exposed to salt water would be protected from corrosion by use of corrosion-resistant alloys, protective coatings, and cathodic protection.

Design of an economical 30-unit power-house of minimum length to fit the available site, and capable of handling a tremendous volume of discharge, indicated use of turbines as large as possible. The turbines selected for the project are the fixed-blade propeller type with a throat diameter of 320 inches and a speed of 40 r.p.m. Due to the low average power head of 11 feet, the large turbines would be directly connected to generators with a relatively low rating of 10,000 kilowatts.

A comparison of the performance of fixed-blade and Kaplan turbines, based on data furnished by United States and Canadian manufacturers, indicated that the greater efficiency of the Kaplan turbine over a wide range of heads was offset by its greater cost. A new type of horizontal-axis turbine-generator unit recently developed in Europe and adopted for use in the single-pool project at La Rance on the northwest coast of France was also studied for possible use in the Passamaquoddy project. The European manufacturer recommended this unit, which can be used as a turbine, pump, or sluice-way, with flow in either direction, as more efficient than conventional units. Power studies showed that the European bulb-type turbine generator develops approximately as much power as the Kaplan, and structural studies indicated a possible saving of $300,000 per powerhouse unit. This saving, however, was offset by the greater cost of the bulb-type turbine-generator set and the need to compensate for low rotative inertia. For these reasons, and because of unresolved maintenance problems, the bulb-type unit was abandoned in favor of the conventional fixed-blade type for the purpose of evaluating the Passamaquoddy project.

The 30 generators would be connected in banks of 7 and 8 to four 90,000 kilovolt-ampere transformers located on the upstream side of the powerhouse and connected to the switchyard by oil-filled high-voltage cables. Two transformers would operate at 230 kilovolts for supply to the United States and two at 138 kilovolts for Canada.



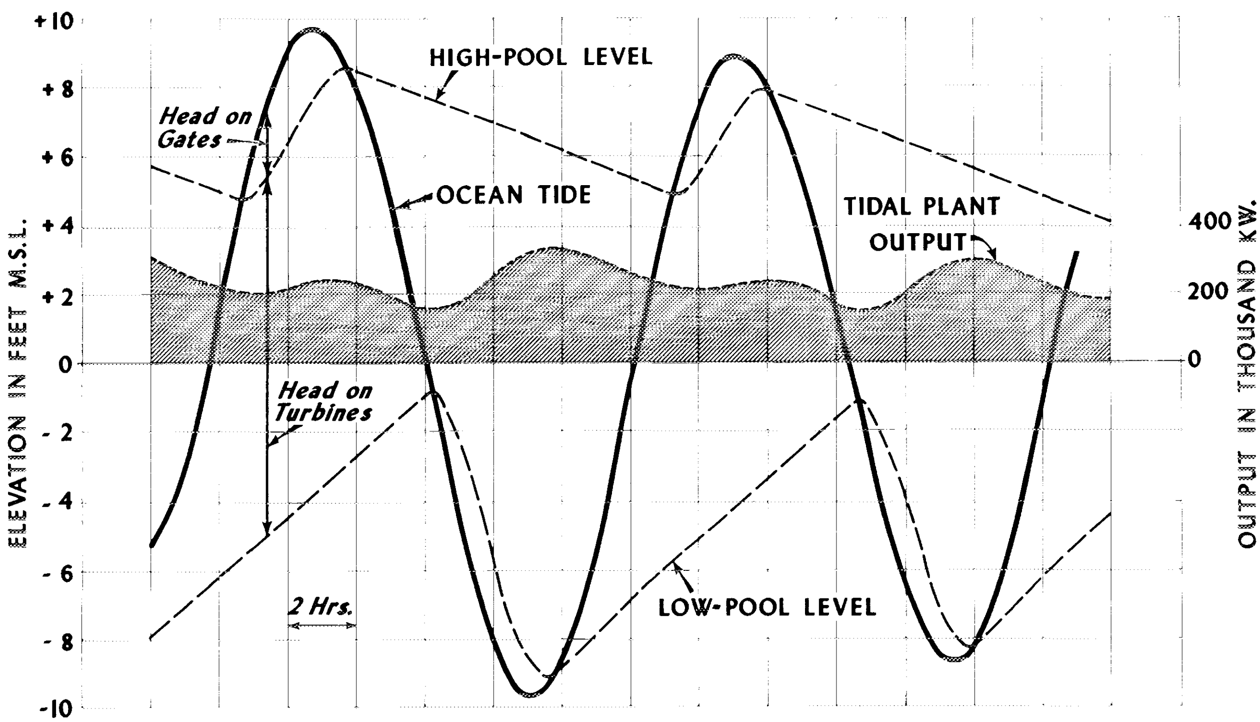
Operation of the powerhouse would be fully automatic. The wicket gate setting of each turbine would be automatically controlled at a pre-determined opening, depending on the gross head on the plant. Synchronizing, loading, and the stopping and starting sequences of each power unit would be controlled automatically by computer punch cards or tapes based on tide predictions. A central control board permitting fully automatic or manual control of all units, as well as the auxiliary power plant, would be located at the center of the powerhouse.

AUXILIARY POWER SOURCES

Each tide would fill the high pool of the tidal power project regardless of the amount of water used to generate energy in the previous cycle. Water left unused would be wasted. Somewhat similar in this respect to a "run-of-the-river" hydroelectric plant where no storage is available, energy generated by a two-pool tidal plant must take full advantage of the ebb and flood of the tides. Because tidal energy must be generated as the tides occur, rather than when the power market requires it, modifying this fluctuating output to meet the demand is essential to the operation of a tidal power plant.

As illustrated in the typical cycle of tidal plant operation, the output of the selected two-pool project would vary with the ebb and flood of the tides. Coupled with the additional variations in tidal range from spring tide to neap tide and the 50-minute difference between the lunar and solar days, this variable output contrasts sharply with the normal pattern of power demand. Hourly, weekly and seasonal variations in the demand for electricity reflect the pattern of activity and life habits of people. Therefore, daily variations in demand, or load patterns, follow the solar cycle which, as previously described, is out of step with the lunar cycle of the tides. At times, therefore, the peak demand for power may coincide with minimum output from the tidal power plant.

For load-carrying purposes, power from the tidal project is limited to the capacity it can furnish under the most adverse conditions. All output in excess of this capacity is not dependable for serving loads. All excess generation would have value only as non-firm or secondary energy. Therefore, to make the maximum output of the tidal power plant dependable, this output must be firmed by an auxiliary source of power.



TYPICAL TIDAL PLANT OPERATION

Several different types of auxiliary power sources were studied to determine the type best suited for making the combined output of the tidal project and its auxiliary match the characteristic load pattern. These studies included river hydroelectric plants, pumped-storage plants, and steam-electric auxiliaries.

Among a number of river hydroelectric sites examined, Rankin Rapids on the upper Saint John River in Maine, about 175 air miles from the tidal project, was selected to provide the best river hydro and tidal power project combination. The Rankin Rapids project, with an embankment 7,400 feet long and 333 feet high, would impound 8.23 million acre-feet, of which 2.80 million acre-feet would be useable storage. With a powerhouse of 8 units, the dependable capacity would be 460,000 kilowatts, and the plant would generate 1,220 million kilowatt-hours annually. Operated in conjunction with the tidal plant, the combined project would have a total dependable capacity of 555,000 kilowatts and would generate 3,063 million kilowatt-hours of energy annually.

As a possible alternative method of operation, Rankin Rapids could be built to carry part of the load in Maine, and to include additional capacity which could be used as needed to supplement the varying tidal project capacity. Energy thus borrowed from Rankin Rapids when using incremental capacity would be repaid when tidal output is greater than the load.

The Rankin Rapids project, with 2.8 million acre-feet of useable storage, would regulate the flow of the Saint John River and would benefit existing and potential hydroelectric plants downstream in New Brunswick. Although regulation by Rankin Rapids would assist in justifying installation of a great amount of additional capacity on the Saint John River, the work of designing and estimating the cost of these potential projects was beyond the scope of the Passamaquoddy tidal power survey. For this reason, only those benefits accruing to the existing installations at Beechwood and Grand Falls, consisting of an additional 180 million kilowatt-hours a year and a small increase in dependable capacity, were credited to the Rankin Rapids-tidal project combination.

Tidal power can also be supplemented by means of a pumped-storage plant. Using power from the tidal plant at times when it is not required to meet load demands, water can be pumped to a higher storage basin and released through turbines as required to meet the load. Since the output of the tidal plant alone would vary from 95,000 to 345,000 kilowatts, a pumped-storage plant with 228,000 kilowatts of installed capacity would provide a dependable capacity of 323,000 kilowatts from the combined project.

The three most favorable pumped-storage sites were investigated, and a site on the Digdeguash River near its outlet to Passamaquoddy Bay east of St. Andrews, New Brunswick, was adopted for design. Useable storage would amount to 204,000 acre-feet, equivalent to an output of 28 million kilowatt-hours. A loss of about 114 million kilowatt-hours of tidal energy a year in the pumping and generating cycles would be partially offset by 30 million kilowatt-hours a year of fresh-water inflow from the Digdeguash River drainage area. Using 400 million kilowatt-hours of energy from the tidal plant for the pumping cycle, the annual energy generation of the Passamaquoddy tidal plant-Digdeguash combination would be 1,759 million kilowatt-hours.

Supplementing tidal power with a steam-electric plant was studied and found to be the least favorable type of auxiliary. Although construction of a steam-electric plant would cost approximately the same as the Digdeguash pumped-storage plant, the added cost of fuel and operation at a low load factor greatly increased the annual cost and precluded further consideration of a steam-electric plant as an auxiliary to the tidal power project.

In summary, four project combinations were selected for evaluation of costs and benefits:

(1) The Passamaquoddy tidal project operated without an auxiliary: Operating alone, the tidal project output would vary from a dependable capacity of 95,000 to a peak of 345,000 kilowatts. Average annual energy generation would be 1,843 million kilowatt-hours.

(2) The tidal project operated in combination with all the power of the Rankin Rapids hydroelectric project: Using the 460,000 kilowatts of dependable capacity and the annual generation of 1,220 million kilowatt-hours from Rankin Rapids, this combination would have a total dependable capacity of 555,000 kilowatts and generate annually 3,063 million kilowatt-hours.

(3) The tidal project supplemented by capacity alone at Rankin Rapids: Assuming that Rankin Rapids were built primarily to serve the utility load in Maine, 260,000 kilowatts of additional capacity could be installed at Rankin Rapids to firm the varying tidal project output. This combination would have a dependable capacity of 355,000 kilowatts, with an annual generation of 1,843 million kilowatt-hours.

(4) The tidal project supplemented by the Digdeguash pumped-storage auxiliary: Using the dependable capacity of 228,000 kilowatts of the pumped-storage auxiliary, this combination would have a total dependable capacity of 323,000 kilowatts with a net annual generation of 1,759 million kilowatt-hours.

The second of these project combinations, the tidal plant operated in combination with all the power of the Rankin Rapids hydroelectric auxiliary, proved to be the most economical. Engineering and economic data on each of the four project combinations analyzed are presented at the end of this syllabus.

POWER MARKETS

Detailed studies were made to determine whether present and potential power markets in Maine and New Brunswick could absorb the project power. Since a power project will have value only to the extent that a demand for power exists, power market surveys were conducted in the Maine-New Brunswick area. The New Brunswick markets were surveyed by The New Brunswick Electric Power Commission, which serves over 90 percent of the people in the Province, and the power markets of Maine were studied by the United States Federal Power Commission.

Power markets consist of rural, urban, residential, commercial, industrial and other electric energy consumers served by utility systems. Requirements for utility-furnished energy are influenced directly by population growth, greater use of energy per customer, expansion of industrial, trade and service activities, and introduction of new uses of electric energy. The aggregate effect is a sustained growth in demand for electric power and a continuing need for adding to the power supply of the utility systems. Thus consumers who could use power from the tidal power project in a definite and predictable way are those now served by public and private utility systems.

In 1957 Maine utilities supplied 2,682 million kilowatt-hours to their customers, with a combined peak demand of 493,000 kilowatts. Power market studies show that energy requirements will reach an estimated total of 4,020 million kilowatt-hours by 1965 and will grow to 7,630 million kilowatt-hours with a peak demand of 1,390,000 kilowatts by 1980.

In 1957 New Brunswick utility requirements amounted to 680 million kilowatt-hours, with an annual peak demand of 152,000 kilowatts. The record of past energy requirements in the Province, however, is one of spectacular growth, particularly in the years following World War II. Between 1940 and 1957 the utility market increased some 450 percent. Further growth can be expected as uses of electricity find wider application with greater industrialization in the Province and exploitation of its mineral resources. According to estimates prepared by The New Brunswick Electric Power Commission, requirements will continue to increase to 1,220 million kilowatt-hours in 1965 and to 3,040 million kilowatt-hours in 1980.

From 1940 to 1957 the energy requirements of the combined markets increased from 1,228 to 3,362 million kilowatt-hours, for an over-all increase of 174 percent. In the same period of time the peak demand increased from 238,000 to 645,000 kilowatts, for a gain of 171 percent. Energy requirements of the combined market will increase to an estimated 8,450 million kilowatt-hours in 1975, and to 10,670 million in 1980, an average annual growth during this five-year period of 440 million kilowatt-hours. Peak demand is expected to increase to 1,590,000 kilowatts in 1975 and to 1,990,000 kilowatts in 1980, an average annual increment of 80,000 kilowatts during this five-year interval.

Total kilowatts of capacity required in addition to that scheduled for installation in the near future to meet the growing utility loads in Maine and New Brunswick, considering reserves and retirements, is shown in the following table.

Year	Maine	New Brunswick	Total
1965	200,000	28,000	228,000
1970	405,000	135,000	540,000
1975	650,000	258,000	908,000
1980	955,000	427,000	1,382,000

Thus, the power market surveys revealed that the need for additional capacity to meet future demands in both Maine and New Brunswick could readily absorb by 1980 the 555,000 kilowatts of dependable capacity from the Passamaquoddy tidal plant and the Rankin Rapids hydroelectric plant on the Saint John River, the largest project combination studied.

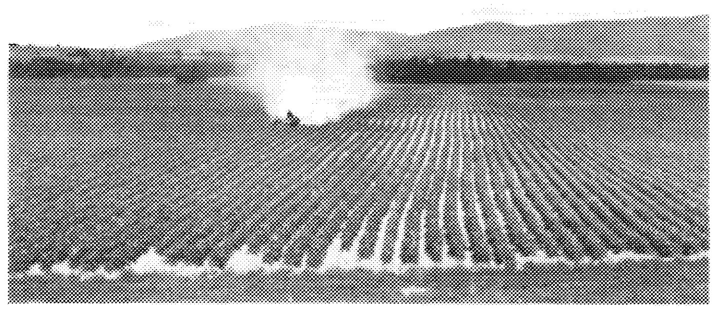
ECONOMIC EFFECTS

In consonance with the objectives of the comprehensive survey, and for purposes of economic analysis of the project, an evaluation was made of all possible beneficial and damaging effects that construction of the tidal project, with and without an auxiliary power plant, may have on the regional and national economies. These studies encompassed all aspects of the general economies, including power markets, manufacturing and industrial growth, the lumber, pulp and paper industries, agriculture, fisheries, recreation, transportation systems and consideration of national defense.

In the State of Maine, the largest income-producing and power-consuming segment of the economy is manufacturing, which includes lumber, pulp and paper production, fish processing, textiles and apparel, leather and leather goods, and food processing. The next largest employed group is engaged in wholesale and retail trade, followed by agriculture, fisheries, recreation, and professional and related services. With the exception of the textile industry, almost all segments of the Maine economy have shown continuous growth. Extensive efforts are being made to attract new and diversified industries into the state.

With 86 percent of the land area of the state in forest, the forest products industry is the most important single element in the state's economy, and the long-time prospects of forest-based industries are favorable, particularly the pulp and paper industry. Agriculture has long been dominated by the potato crop of Aroostook County. Despite rising output in other parts of the country, Maine has maintained its position as the leading potato-producing state by attaining greatly increased yields on a reduced acreage. An important recent development in Maine agriculture is that the growth of poultry production has surpassed the potato crop as the leading source of farm income. The long-established fishing and fish processing industry has produced higher personal income in recent years due to the growth in demand for more expensive fish, particularly the valuable lobster catch.

Important future growth is also expected in the recreation industry of Maine, which in 1959 ranks as the second largest income-producing activity in New England as a whole. The value of the recreation industry in Maine rose from $135 million in 1950 to $272 million in 1957. The Passamaquoddy tidal power project, which would be the first large-scale tidal power plant in the western hemisphere, and perhaps the first in the world, would attract a great number of visitors. Had the tidal project been in existence in 1957, an estimated 800,000 visitors from the United States and Canada would have been attracted to the area.



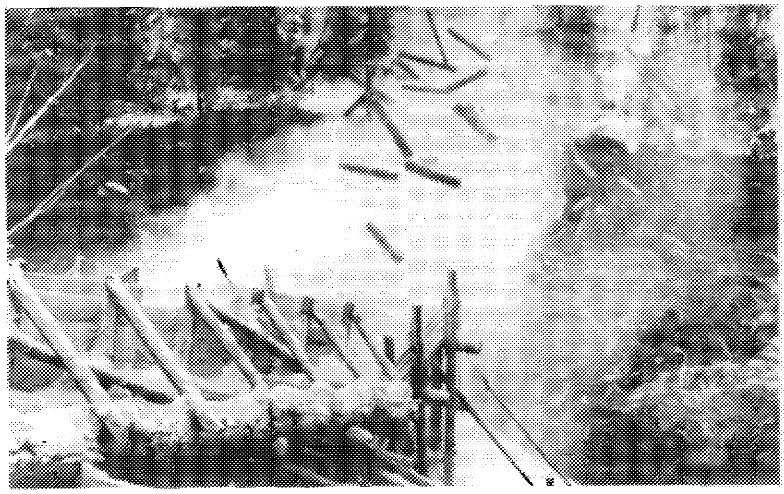
Spraying a potato field

In addition to the fact that the growing power markets of Maine can readily absorb all project power by 1980, other important advantages in Maine should encourage more rapid economic growth. The State has a large labor force of high quality. In 1956 non-agricultural employment amounted to 281,700, of which nearly 39 percent were engaged in manufacturing -- a considerably higher percentage than the United States average. Native ingenuity, versatility, sense of responsibility, and productivity, as well as a higher than average educational level, make this labor force readily adaptable to new employment opportunities.

At present, rail and commercial air transport are adequate and stimulating to economic communication among all parts of the State. The highway system is not only adequate and modern, but is keeping well ahead of requirements. In the field of coastal and overseas transport, Maine has many superb harbors which were the basis of her prosperous economy during the nineteenth century and which, today, because of relative proximity to Europe, the St. Lawrence Seaway, and leading eastern ports, constitute a great economic potential.

Other advantages in Maine attractive to new enterprises are the availability of suitable industrial sites; abundant supplies of fresh water; access to overseas raw materials; favorable and cooperative local governments and business organizations; and proximity to leading academic, professional, and research centers throughout New England.

Construction of the tidal power project and its auxiliary power plant would have a favorable impact on all segments of the economy of Maine. As well as assisting to supply the needs of the growing power markets in the state, construction and operation of the tidal project and its auxiliary would serve to regenerate the economy of Maine, particularly in Washington County. In addition to long-term beneficial effects, construction of the tidal power project alone would also produce an important short-term impact on the economy of Maine resulting from an investment of $100 million or more. The economy of Washington County would be transformed during the six-year construction period of the project by the influx of several thousand workers and the generation of substantial new income from wages alone.



Pulpwood chute

As reflected in the power market and economic surveys, considerable growth is expected in the economy of New Brunswick. Manufacturing, the leading economic activity of the Province, is based on pulp and paper, the lumber and wood-using industries, minerals, and fishing and fish processing. Other major segments of the economy are agriculture, construction, secondary manufacturing, food processing, the recreation industry and professional and other services.

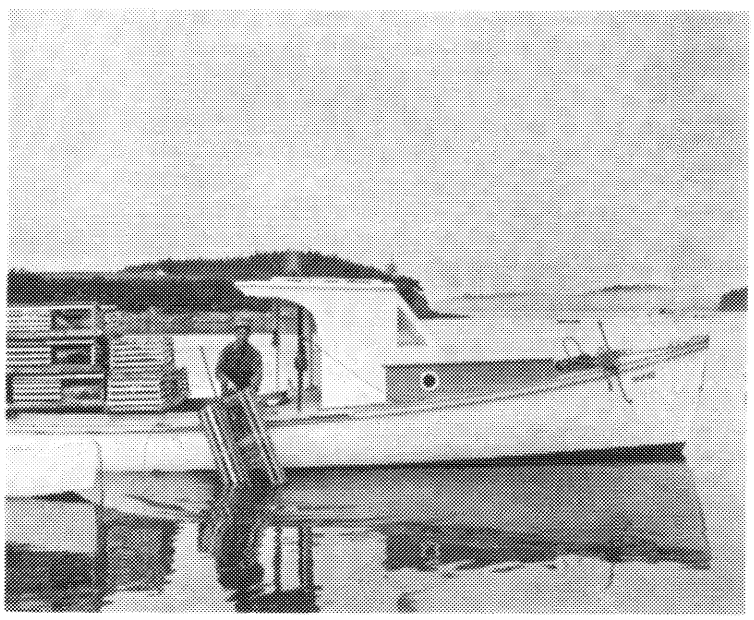
Rapid growth is expected in almost all segments of the Provincial economy. Long-term economic growth, however, is expected to be most pronounced in resource-based industries that manufacture for export. Pulpwood and paper production, based on the vast timber resources of the Province, is economically the most important industry and is expected to double by 1980. Canada's domestic market for pulp and paper products is growing rapidly, and market prospects in the United Kingdom and Western Europe appear equally favorable.

Exploitation of the recently discovered deposits of base metals in the Bathurst-Newcastle area is also expected to stimulate the economy. The discovery of lead, zinc, copper, and silver is of major economic importance, and by 1980 mineral production is expected to be second only to the pulp and paper industry as an employer and in value of product. Large deposits of high-grade ores, suitably located near tidewater, have already brought about a sizeable investment of external capital, and one 1,500-ton per day concentrating mill has been put into operation.

Important growth is also expected in the fishing and fish processing industries. Shellfish, particularly lobsters, constitute a substantial part of the total market value. Sharply increased ouput through mechanization and the growth of by-product use is expected to stimulate the future growth of the fishing industry.

Because manufacturing in areas other than mineral, forest, and fish processing is not highly developed in New Brunswick, the efforts of the Maritime Provincial Governments and the Maritime Boards of Trade to attract new industries to New Brunswick have led to the formation of the Atlantic Provinces Economic Council. With well-developed transportation systems, port facilities, a growing and dependable labor force and other assets, the future development of secondary industries in the Province can be expected.

The tourist industry is recognized as a growing segment of New Brunswick's economy, income from which is estimated to be from 30 to 40 million dollars annually. A total of 1,370,000 people visited the Province in 1958. Construction of the Passamaquoddy tidal power plant, by attracting an estimated 800,000 or more visitors each year from the United States and Canada, would further increase the recreation industry.



Lobster fishing

The economic effect of the tidal project in New Brunswick resulting from the addition of a large block of power from the tidal project and its auxiliary would be similar to that of any other block of power of equal size and cost developed to satisfy the growing load demand. The short-term economic benefits to the economy of Charlotte County would be substantial. Construction of the project, with attendant expenditures of $100 million or more to purchase materials and equipment, would have a stimulating effect on the provincial economy. Substantial new income could be expected to stimulate retail trade, and construction of the project would improve the lumber industry in the county.

Inherent in the name "Passamaquoddy," derived from the Indian word "Peskutumaquahdik," meaning "place where the fish are," or "place of the pollock," is the importance of the fisheries in the waters within the tidal project area. On the recommendations of the International Passamaquoddy Fisheries Board, two fishways to pass anadromous fish from the ocean into Passamaquoddy and Cobscook Bays, and the relocation, if necessary, of two lobster pounds in the upper pool, were included in the tidal project. By including these remedial measures, the tidal project would have only a minor residual effect on the fisheries of the region.

Since the tidal project would raise the level of the Passamaquoddy Bay high pool and decrease the tidal range, navigation conditions would be improved in the St. Croix River estuary and at St. Andrews and other ports on Passamaquoddy Bay. In the low pool in Cobscook Bay, on the other hand, the beneficial effects of decreasing the tidal range would be partially offset by lowering the maximum level of the low pool to a point below the level of normal high tide. Navigation in the lower pool in the Falls Island and Lubec area, where rapid tidal currents occur, would be improved during a considerable portion of the tide cycle. While the lower pool is being emptied, however, tidal velocities would occur equal to those under present conditions. In general, tidal velocities in the project area would be reduced, except in areas immediately adjacent to the gates when open.

Construction of the tidal power project would require relocation of part of State Highway 190, one track of the Maine Central

Railroad, and water lines and other utilities coming from the north to Eastport, Maine. These utilities would be cut by the powerhouse forebay channel excavated through the narrow neck of Moose Island. The cost of these relocations, which would require construction of a highway and railroad bridge across the powerhouse forebay, would be charged to the power project.

Construction of the dams, locks and gates would provide foundations on which a system of public highways could be built to serve both the United States and Canada.

The defense agencies of both United States and Canada concluded that construction of the tidal power project would have no effect on defense planning. It is estimated, however, that the annual energy of 3,063 million kilowatt hours generated by the Passamaquoddy tidal plant in combination with the Rankin Rapids hydroelectric plant would save 1,280,000 tons of coal, or approximately 5,700,000 barrels of oil, during each year of operation. This would preserve 64 million tons of coal, or 585 million barrels of oil, over a 50-year period.

PROJECT EVALUATION

The benefits of the tidal power project must exceed the cost to the taxpayer if it is to be economically sound. Accordingly, the economic justification of the project depends upon whether its power can be produced more economically than the least costly alternative method of developing an equivalent amount of power.

Estimates of the cost of the tidal project and its auxiliaries are based on United States currency at price levels of January 1958. Estimated project costs were derived from the basic costs of labor, equipment, material and supplies as applied to the pre-determined construction method planned for each major feature of the project. Equipment costs, based on manufacturers' quotations in both countries, are taken to be duty free, although appropriate import duties were used for comparison with equipment costs from foreign sources. The first cost, or construction cost, includes an allowance for 10 percent profit, 15 percent for contingencies, and 9 percent for engineering, supervision and overhead. The cost of transmission lines were not included in the first costs, but have been accounted for in the evaluation of the project. On this basis, the first cost of each of the four project combinations, not including interest during construction, is as follows:

(1) Passamaquoddy tidal project alone $484,000,000

(2) Tidal project with all of Rankin Rapids as auxiliary $630,000,000

(3) Tidal project with auxiliary capacity only at Rankin Rapids $515,500,000

(4) Tidal project with Digdeguash pumped-storage auxiliary $518,500,000

It is assumed that the financing of each project would be an undertaking of the two governments, and that the first cost of the project would be shared equally between the United States and Canada, just as the power is equally shared. The degree of economic justification is measured by the ratio of annual benefits to annual costs. Annual costs of the tidal project and its auxiliary include interest and amortization of the initial investment and the annual cost of operation and maintenance.

In accordance with the current Federal practice in evaluating water resource projects, the interest rate used for economic analysis in the United States is 2 1/2 percent. In Canada the interest rate is 4 1/8 percent, which was the rate used in January 1958 by the Federal Government of Canada. Therefore, differences in interest rates and power values between the two countries led to computation of separate benefit-cost ratios for each country. The investment is amortized over two periods, 50 years and 75 years, with allowances made for periodic major replacement and self insurance.

Power benefits, the value of power produced by the tidal project and its auxiliary, are taken as equal to the cost of power generated by a steam-electric plant, with allowances for transmission lines and annual transmission costs. Alternative steam-electric plants were assumed privately financed in the United States, and financed by The New Brunswick Electric Power Commission in Canada.

Thus the ratio of benefit to cost for each of the four project combinations was computed by dividing the total annual benefits by the annual costs.

CONCLUSIONS

(1) A tidal power project using the waters of Passamaquoddy and Cobscook Bays can be built and operated. The two-pool type of project is best suited for the site conditions in the area and the power markets it would serve. The tidal project arrangement selected makes best use of the site conditions.

(2) The first cost (construction cost) of the tidal power project by itself would be $484 million. With interest during construction, the investment would be $532.1 million. The tidal power project would have an installed capacity of 300,000 kilowatts and a dependable capacity of 95,000 kilowatts. Average annual energy would be 1,843 million kilowatt-hours. However, for maximum power benefits, the tidal power project would have to be combined with an auxiliary power source.

(3) The most favorable project combination is the tidal power project operated in conjunction with a river hydroelectric auxiliary built at the Rankin Rapids site on the upper Saint John River in Maine. The combined cost of the tidal project and the Rankin Rapids auxiliary is $630 million. With interest during construction, the investment would be $687.7 million. The dependable capacity of this combination would be 555,000 kilowatts, and average annual generation would be 3,063 million kilowatt-hours.

(4) Construction of the tidal project - Rankin Rapids combination would increase low flows in the lower Saint John River by a considerable amount, thus increasing substantially the usefulness of the river for downstream generation of power. Downstream benefits accruing to existing power plants were included in the economic evaluation.

(5) The combination of the tidal power project and the installation and use of 260,000 kilowatts of capacity only at Rankin Rapids for firming up the output of the tidal power project would cost $515.5 million. With interest during construction, the investment would be $565.7 million. This combination would provide a total dependable capacity of 355,000 kilowatts and an average annual generation of 1,843 million kilowatt-hours.

(6) The tidal power project and the Digdeguash pumped-storage auxiliary would cost $518.5 million. With interest during construction, the investment would be $568.9 million. The dependable capacity would be 323,000 kilowatts, and average annual generation would be 1,759 million kilowatt-hours.

(7) The total output from the tidal power project and Rankin Rapids hydroelectric plant can be absorbed readily by the growing utility markets of Maine and New Brunswick.

(8) Because of differences in interest rates prevailing in the two countries, and because of different values of alternative power, it was necessary to compute separate benefit-cost ratios for United States and Canada. Economic evaluations, assuming 50-year and 75-year amortization periods, and assuming that power output and project first cost would be equally divided between the United States and Canada, are tabulated below:

	50-year amortization		75-year amortization	
	Benefit cost ratio	Cost per kw.-hr., (mills)	Benefit cost ratio	Cost per kw.-hr., (mills)
Tidal project alone				
United States	0.60	10.8	0.70	9.3
Canada	0.34	14.9	0.37	13.7
Tidal project and all of Rankin Rapids				
United States	1.31	8.4	1.53	7.2
Canada	0.58	11.5	0.63	10.6
Tidal project and incremental capacity only at Rankin Rapids				
United States	0.93	11.5	1.08	9.9
Canada	0.42	15.8	0.45	14.5
Tidal project and Digdeguash pumped-storage auxiliary				
United States	0.91	12.2	1.06	10.5
Canada	0.42	16.8	0.46	15.4

(9) The inclusion of taxes foregone with project costs is not the practice in the economic justification of public projects in Canada, and due to the international nature of the project, such taxes have not been applied to United States' costs. However, if they were included in United States' costs, the benefit to cost ratio of the most favorable project combination would be reduced to 1.10 for the 50-year amortization period and to 1.25 for the 75-year period.

(10) By including appropriate remedial measures in the design of the tidal power structures, the construction, maintenance and operation of the tidal power project would have only a minor residual effect on the fisheries of the region.

(11) Considerable annual recreation benefits would grow out of the construction and operation of the tidal power project. However, the monetary value of these benefits was not included in the economic evaluation.

(12) Assuming an equal division of power output and of first costs between United States and Canada, construction of the tidal power project with all of Rankin Rapids as auxiliary is not an economically justified project for Canada.

(13) The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States at an interest rate of 2 1/2 percent, is economically justified.

PERTINENT DATA

PASSAMAQUODDY TIDAL POWER PROJECT

Location

Passamaquoddy Bay and Cobscook Bay, in Maine and New Brunswick.

High Pool

Passamaquoddy Bay, Maine, and New Brunswick.

Area, sq. mi.	101
Max. operating level, ft., m.s.l.	12.2
Min. operating level, ft., m.s.l.	3.0

Low Pool

Cobscook Bay, Maine, and Friar Roads, New Brunswick.

Area, sq. mi.	41
Max. operating level, ft., m.s.l.	0.0
Min. operating level, ft., m.s.l.	-12.9

Powerhouse

Outdoor type; two 220-ton gantry cranes; thirty 320-inch diameter fixed-blade, propeller type, vertical-axis turbines direct connected to 10,000-kw., 13,800-volt, 3-phase, 60-cycle generators turning at 40 r.p.m.; average power head 11 feet.

Dams

Earth and rockfill type	
Total length, ft.	35,700
Max. height, ft.	315
Crest elevation, ft., m.s.l.	25

Filling and Emptying Gates

Ninety 30- x 30-foot vertical-lift, submerged venturi filling gates. Seventy 30- x 30-foot vertical-lift submerged venturi emptying gates.

Navigation Locks

Head Harbour Passage, ft.	415 x 60 x 21
Western Passage, ft.	415 x 60 x 21
Little Letite, ft.	95 x 25 x 12
Quoddy Roads, ft.	95 x 25 x 12

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	53,000,000
Cofferdams, cu. yd.	12,000,000
Misc. fill, cu. yd.	1,000,000
Waste, cu. yd.	9,000,000
Concrete, cu. yd.	1,473,000
Steel, tons	182,000

RANKIN RAPIDS HYDRO AUXILIARY

Location

Saint John River, Maine, 291 miles above mouth.

Streamflow

Ave. annual runoff, ac.-ft.	4,950,000
Max. discharge, c.f.s.	90,400
Min. discharge, c.f.s.	373
Ave. discharge, c.f.s.	6,780

Reservoir

Drainage area, sq. mi.	4,060
Max. operating level, ft., m.s.l.	860
Limit of drawdown, ft., m.s.l.	823
Useable storage, ac.-ft.	2,800,000
Total storage, ac.-ft.	8,230,000
Area, max. operating level, ac.	93,300

Main Embankment

Crest length, ft.	7,400
Max. height, ft.	333
Crest elevation, ft., m.s.l.	875

Spillway

Six 30- x 40-foot taintor gates	
Crest elevation, ft., m.s.l.	830
Design discharge, c.f.s.	167,000

Low Level Outlets

Two 24-foot diameter tunnels controlled by four 90-inch fixed-cone dispersion valves.

Powerhouse

Indoor type, concrete. Eight Francis-type, vertical-axis turbines, ave. head 284 ft., direct connected to 50,000-kw., 13,800-volt, 3-phase, 60-cycle generators turning at 164 r.p.m.

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	33,000,000
Miscellaneous, cu. yd.	1,500,000
Concrete, cu. yd.	400,000
Structural steel, tons	19,000
Reinforcing steel, tons	12,000

DIGDEGUASH PUMPED-STORAGE AUXILIARY

Location

Mouth of Digdeguash River, New Brunswick.

Streamflow

Ave. annual runoff, ac.-ft.	265,000

Reservoir

Drainage area, sq. mi.	176
Max. operating level, ft., m.s.l.	180
Min. operating level, ft., m.s.l.	140
Useable storage, ac.-ft.	204,000
Total storage, ac.-ft.	308,500

Embankments

Impervious core, rock-shell.

Total length, ft.	5,500
Max. height, ft.	190

Powerhouse

Indoor type, concrete. Four adjustable feathering-blade pump-turbines; mean pumping head 158 ft.; mean generating head 154 ft. Four motor-generators, 100 r.p.m., rated at 84,300 h.p., 13.8 kv., as motors; 68,300 kv.-a., 13.8 kv., 0.95 P.F., as generators.

Spillway

Three 25- x 40-foot taintor gates

Crest elevation, ft., m.s.l.	155
Design discharge, c.f.s.	75,000

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	1,881,000
Miscellaneous, cu. yd.	269,000
Concrete, cu. yd.	130,000
Structural steel, tons	3,000
Reinforcing steel, tons	2,400

POWER OUTPUT AND CONSTRUCTION COST

In this table it is assumed that power output and project first cost would be shared equally by the United States and Canada. The initial investment includes 2 1/2 percent interest during construction on the United States' share of the first cost and 4 1/8 percent interest on Canada's share of the first cost. **Costs are based on price levels of January 1958.**

Project Combination	Dependable capacity (kw.)	Average annual generation (millions of kw.-hr.)	Total project first cost (millions of dollars)	Initial investment (millions of dollars) United States	Canada
Tidal project alone	95,000	1,843	484.0	260.2	271.9
Tidal project and all of Rankin Rapids	555,000	3,063	630.0	336.8	350.9
Tidal project and incremental capacity only at Rankin Rapids	355,000	1,843	515.5	276.8	288.9
Tidal project and Digdeguash pumped-storage capacity	323,000	1,759	518.5	278.4	290.5